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AN EXPERIMENTAL EXAMINATION ON NONSTATIONARY BEHAVIOR IN SIMULA--ETC(U)

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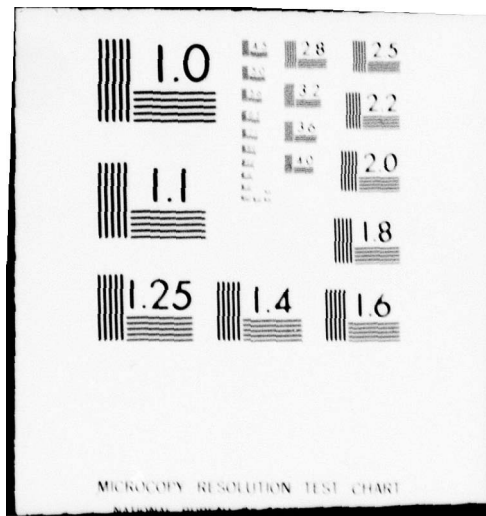
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19. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report is the third and final in a series of studies by Dr. L. Schwarz concerning an investigation of U.S. Air Force policies for managing depot-base inventories of non-repairable spares. The first study titled, "An Examination of the U.S. Air Force (Q, R) Policies for Managing Depot-Base Inventories: A Pilot Study" (ADA031485), evaluated and compared current Air Force EOQ policy with three alternative policies via computer simulation. The three alternative policies examined were: (1) the		

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system myopic variant to current Air Force policy, (2) the allocation policy, and (3) the "depot only" policy. Two questions were examined. First, is it possible to formulate an alternative policy which has the same desirable properties of current Air Force policy (ease of computation and implementation) but which is somewhat closer to optimal from a cost and/or backorder performance standpoint? Second, is it possible to formulate an alternative policy which has most of the desirable properties of current policy, but which is substantially closer to optimal from a cost and/or backorder performance standpoint? Based on a very small sample size, both questions were affirmative.

The second study (ADA031486) used demand history for a sample of 50 items that were currently stocked by the Ogden and Oklahoma City Air Logistics Center (depots systems). This paper evaluated the two most promising alternative policies: system myopic policy and allocation policies.

Operating performance measures were: (1) average annual order plus holding cost; (2) average annual order plus acquisition cost; and (3) average annual backorder-days at the bases. The report concludes that, at least under certain circumstances, system operating performance may be improved, perhaps substantially, by adoption of either of the proposed alternative policies. However, during the later part of the operating performance test period significant non-stationarities emerge.

A third study was then initiated. This report titled, *An Experimental Examination of Non-Stationary Behavior in Simulated Tests of Alternative Policies for Managing the USAF (Q, R) Depot-Base Inventories,* extends the second report. In this extension a set of four experiments are conducted which are designed to investigate the feasibility of reducing or eliminating the non-stationarity of the test conducted in the previous study. Implications of the tests and alternatives are provided in the report.

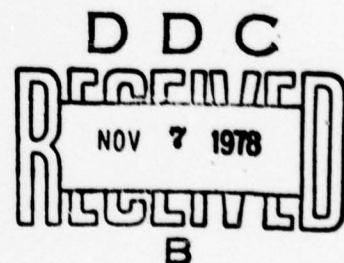
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"An Experimental Examination
of Nonstationary Behavior in Simulated
Tests of Alternative Policies for
Managing the USAF (Q,R) Depot/Base Inventories"

by

Leroy B. Schwarz

December 28, 1977



Prepared for: Air Force Business Research Management Center
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I. Introduction

This report extends the study reported in "An Examination of the United States Air Force (Q,R) Policies for Managing Depot/Base Inventories," [1]. Reference [1] examined the operating performance of three different policies: CURRENT, the current Air Force (Q,R) policy; MYOPIC, a system myopic variant of CURRENT; and ALLOCATION, an allocation oriented variant of CURRENT. See [1] for details. The examination in [1] was conducted via computer simulation using the demand history of 4 years for a sample of 50 items supplied by the Air Force Logistics Command, in cooperation with the Business Research Management Center. The conclusions in [1, p. 21] were: "...the tests described here indicate that CURRENT policy may be improved, perhaps significantly, by adoption of either the MYOPIC or the ALLOCATION policies." However, these conclusions were heavily qualified by the nonstationarity of system behavior during the test period. In particular, backorder-day performance was extremely nonstationary. See Figure 4 of [1]. As stated in [1, pp. 18-21]:

"The implications of this nonstationarity are twofold: First, the typical tests used to analyze empirical data may not be applied Second, and more important, the nonstationarity implies that the system was possibly not behaving "typically" during the test period ... the observed relative ... performance of the three tested policies might have been different had data been available to test the performance of the policies over a period of more ... years."

This report describes a set of four experiments designed to investigate the feasibility of reducing or eliminating the non-

stationarity of the tests conducted in [1]. These four experiments are described and analyzed in each of the four following sections, II - V. Section VI describes our conclusions and suggestions for further study.

II. Experiment 1: Initial Conditions

Among the possible causes of the nonstationarity observed in [1] was the procedure used to initialize on-hand inventories at the beginning of the simulation. As described in [1, p. 9]:

"For each of the three policies tested, the system was initialized as follows: the first two years (8 quarters) of the supplied depot demand history were used to compute the values of: (i) mean daily base demand; (ii) mean monthly depot demand; and (iii) the quarterly depot MAD required to compute the initial (Q,R) values for each item to be used by the depot and bases. The system was then initialized by setting depot inventory for each item equal to one-half the calculated depot Q plus lead time demand ... plus an additional month's supply. Base inventory for each item was set equal to one-half the calculated base Q plus lead time demand ... Initial pipeline inventories (outstanding depot and base orders) were set equal to zero."

It is possible, however, that this initialization procedure could set on-hand inventories (and consequently, inventory position) for a given item at a given location below its reorder point, R. If so, inventory position would be initialized at a value below that corresponding to a representative real world situation. The system would thus be short of inventory for the given item, and consequently, susceptible to backorders in the early quarters of the simulation. Moreover, given the long lead times for some items, these backorders could remain unsatisfied for a very long time, accumulating a very large number of backorders in the process.

In order to investigate the influence of initial inventory on the

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nonstationary behavior of the system, the simulation tests conducted in [1] were repeated (for $\lambda = 113.25$), the same items, the same demand patterns, etc., except that on-hand inventory for each item at each stage was initialized by selecting a value from a uniform probability distribution with lower bound R and upper bound $Q + R$, $U[R, Q + R]$. The revised initialization eliminates all possibility of inventory position being initialized below its reorder point, and correspondingly eliminates, the adverse effect on backorder-day performance. It should be noted, however, the revised initialization procedure could set initial on-hand inventories above those corresponding to a representative real world situation, particularly for items with long lead times and small Q values (lead time \gg lot size/demand rate). Nonetheless, the impact of this inappropriate initialization, if it should occur, should not extend beyond the initialization period (quarters 1 - 8) and into the test period (quarters 9 - 16).

The results of the tests are given in Table 1 and Figure 1. Table 1 reports the average annual performance measures for the two year test period (quarters 9 - 16): Order + Holding Costs, Order _ Acquisition Cost, Acquisition Cost, and Backorder-Days. In addition, the average number of partial shipments 1 year from the depot is reported,¹ as is the initial (beginning of quarter 9) and final (end of quarter 16) dollar asset positions of the system simulated under each policy. For comparison purposes the corresponding measures from [1] are also reported in parentheses.

Analysis of Table 1 indicates that how the system is initialized

¹ As described in [1], if the depot is unable to supply a given base's full requisition a partial shipment is made.

Table 1
Average Annual Performance Measures (n = \$113.25)
Original Sample of 50 Items

Policy	Order + Holding Cost	Order + Acquisition Cost	Acquisition Cost	Backorder-Days	Partial Shipment ¹	Asset Position		Difference
						Initial	Final	
CURRENT	\$151,364	\$1,024,409	\$967,321	1,737,708	2,006	\$458,177	\$451,153	-\$7,024
	(188,371)**	(1,269,614)	(1,223,472)	(1,958,780)	(N. A.) **	(N. A.)	(N. A.)	(N. A.)
	164,591	1,005,047	952,330	1,750,134	1,480	502,708	504,132	1,424
MYOTIC	(158,139)	(1,140,370)	(1,095,160)	(1,836,030)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
	151,334	1,024,409	967,321	1,741,108	2,038	458,177	453,078	- 5,099
	(191,963)	(1,326,660)	(1,277,008)	(1,741,108)	(N. A.)	(N. A.)	(N. A.)	(N. A.)
ALLOCATION								

* Entries in parentheses are the corresponding measures from [1].

** Not available.

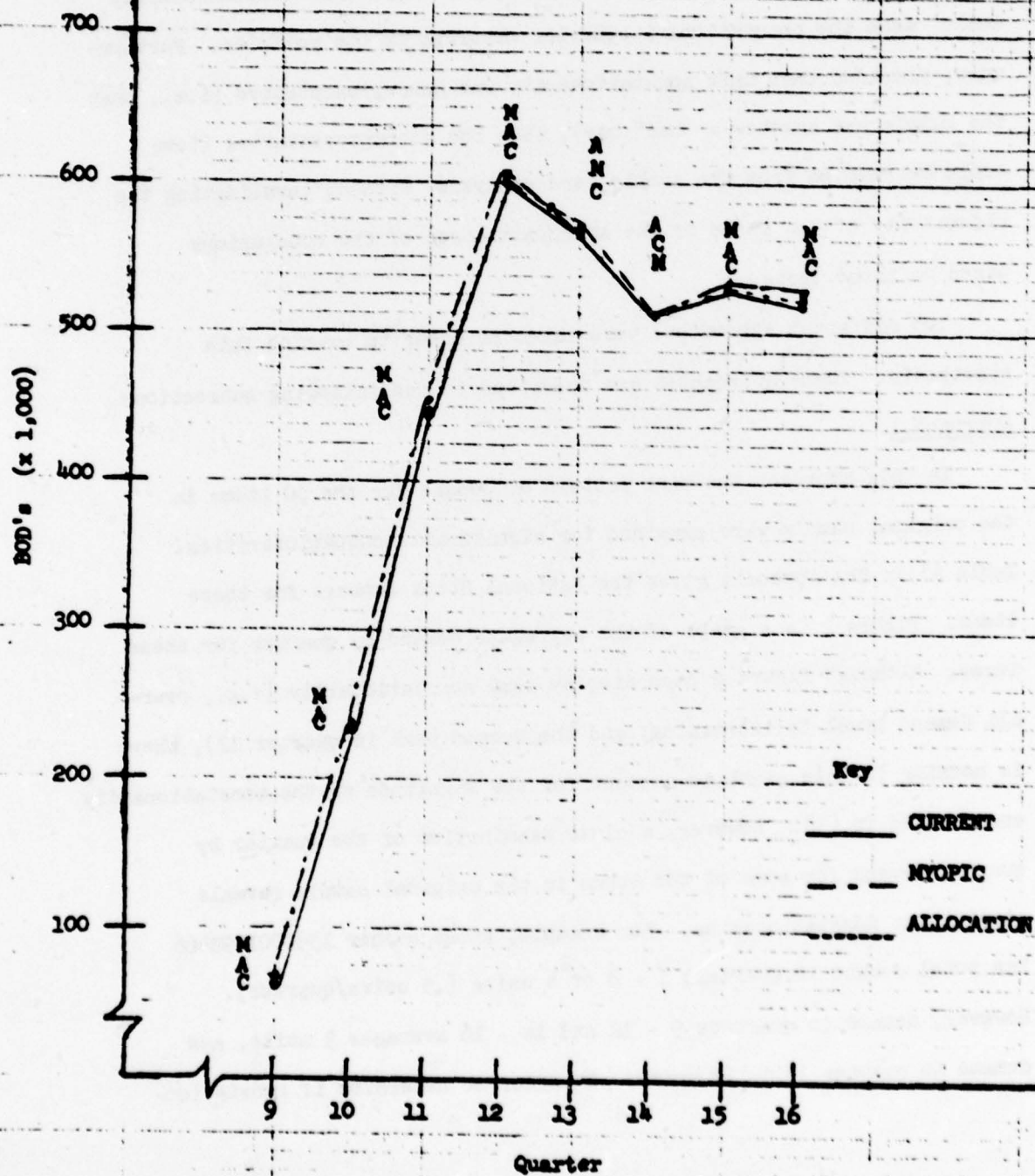
does have an impact on the measures of system performance. For example, order + holding cost for CURRENT changed from \$188,371/year using the original initialization to \$151,364/year using the $U[R, Q + R]$ initialization. The general pattern is as follows: acquisition costs are lower using $U[R, Q + R]$; order costs are higher using $U[R, Q + R]$; holding costs are lower using $U[R, Q + R]$. Most important, the relative performance of the policies is different. Using the original initialization, both the ALLOCATION and MYOPIC policies were superior to CURRENT. See Table 1 and [1, Figure 1]. However, using the $U[R, Q + R]$ initialization this is no longer the case. For example, the order + holding cost of CURRENT and ALLOCATION are virtually identical (\approx \$151,350), but ALLOCATION has more backorder-days (1,741,108) than CURRENT (1,737,708). The MYOPIC policy has higher order + holding costs (\$164,591 vs \$151,364) and higher backorder-days (1,750,134 vs 1,737,708).

Curiously enough, despite the impact of initialization on the relative performance of the policies, the revised initialization had virtually no effect on the nonstationary behavior of the policies over the test period. Figure 1, which plots backorder-days for each policy by quarter displays virtually the same nonstationary behavior as Figure 4 in [1].

Conclusion Based on Experiment 1

The initialization procedure evidently can have a significant effect on the relative performance of the alternative policies. However, the initialization procedure evidently has no significant effect on the nonstationary behavior of the policies over time. These conclusions and their impact on necessary future investigations are discussed in Section VI.

FIGURE 1



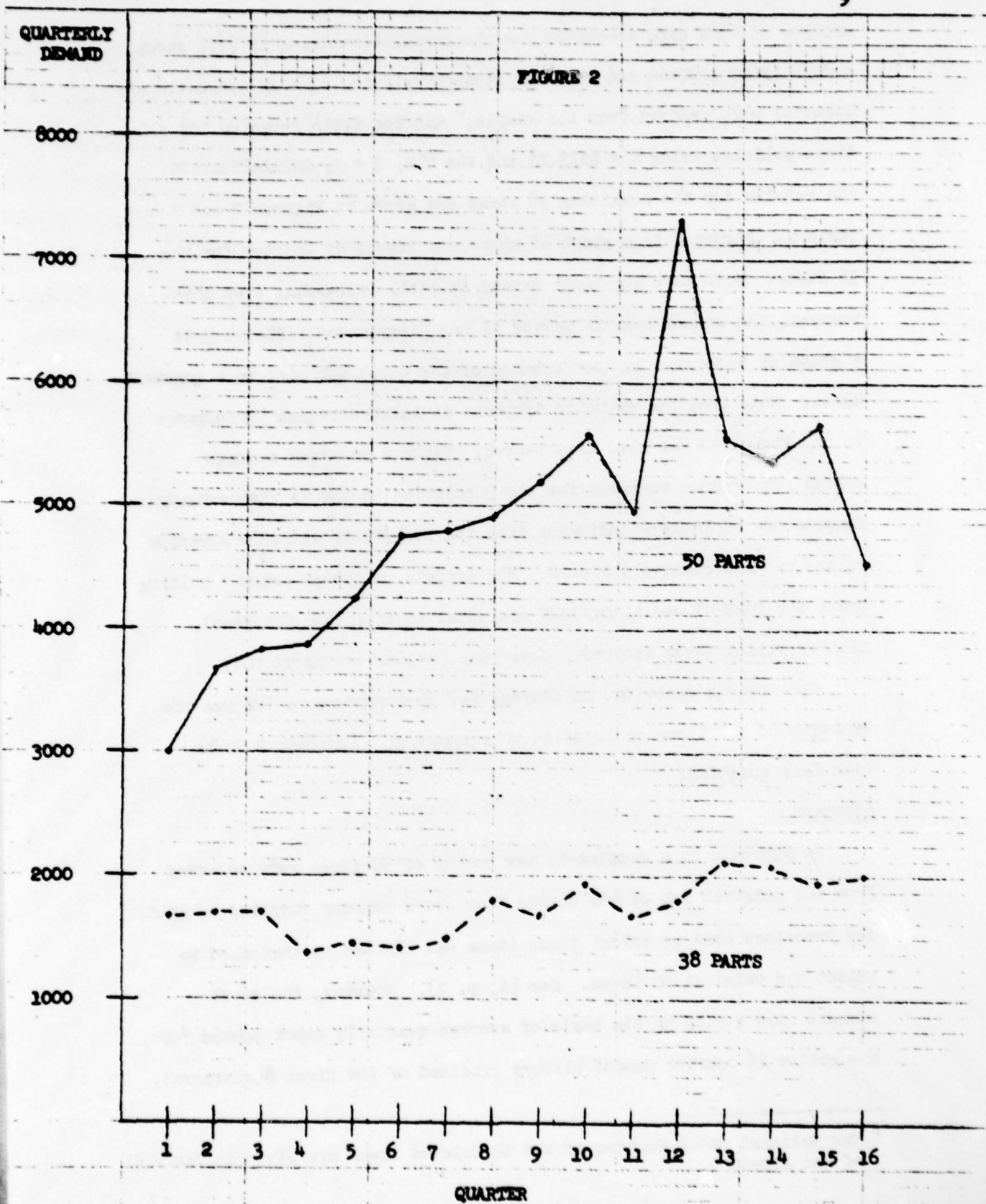
III. Experiment 2: Sample Data

A second hypothesized cause of the nonstationarity observed in [1] lies in the nature of the demand pattern of the 50 items originally sampled. The hypothesis was: if the demand pattern for some or all of the items in the original sample was nonstationary, this nonstationarity could cause the nonstationary behavior observed in the policies. Furthermore, provided that this nonstationarity was nonrepresentative (i.e., that the sample was somehow a "bad" one), then the nonrepresentative items could be removed from the sample (and analysis) without invalidating the objectivity of the tests or the appropriateness of the conclusions based on those tests.

Two different approaches were taken in order to examine this hypothesis. These approaches are described in the following subsections.

Approach 1

In this approach the time pattern of demand for the 50 items in the original sample were examined for significant nonstationarities. Table A1 in the Appendix gives the National Stock Numbers for these items. Figure 2 is a graph of the aggregate demand by quarter for these items. Although Figure 2 does display some nonstationarity (e.g., overall demand level is increasing; and the demand peak in quarter 12), there is nothing in this graph to account for the magnitude of the nonstationarity encountered in [1]. However, a close examination of the quarter by quarter demand for some of the items in the original sample reveals significant nonstationaries. For example, stock number 1560001092466 has total demand in quarters 1 - 8 of 4 units (.5 units/quarter). However, demand in quarters 9 - 12 and 14 - 16 averages 3 units, and demand in quarter 13 is 32 units! In order to determine if nonstation-



arities of this type accounted for the nonstationarities in [1], stock number 1560001092466 and 11 other items displaying similar nonstationary behavior were removed from the sample,² and the tests repeated for all three policies using $\lambda = \$113.25$ and the $U[R, Q + R]$ initialization. The results for the remaining 38 items are given in Figures 2 and 3 and Table 2. Figure 2 is a graph of aggregate demand by quarter for the 38 items. Note that aggregate demand is still increasing over time. However, the demand peak in period 12 has disappeared. Figure 3 is a graph of backorder-day performance of the three policies on a quarterly basis. Note that the dramatic increase in backorder-days performance in [1, Figure 4] has also disappeared. Table 2 provides average annual performance measures for the 3 policies on the 38 item subsample. Examination of Table 2 indicates that the CURRENT is slightly superior to the two alternative policies. For example, although order + holding costs for CURRENT and ALLOCATION are about equal ($\approx \$46,200/\text{year}$), CURRENT yields fewer backorder-days/year (47,662 versus 53,464).

The obvious question, of course, is: how representative was the behavior of the items excluded in this approach. Approach 2 deals with this question.

Approach 2

In Approach 2, a completely new sample of 50 items were selected from the original set of 461 usable item stock numbers supplied by AFLC. The procedure used to select these items was similar to that used to select the original 50 items. See [1, p. 7]. However, the stock numbers were sorted on the basis of average quarterly depot demand for the entire 16 quarter demand history (instead of the first 8 quarters).

² The National Stock Numbers of the 12 deleted items are given in Table A1 of the Appendix.

FIGURE 3

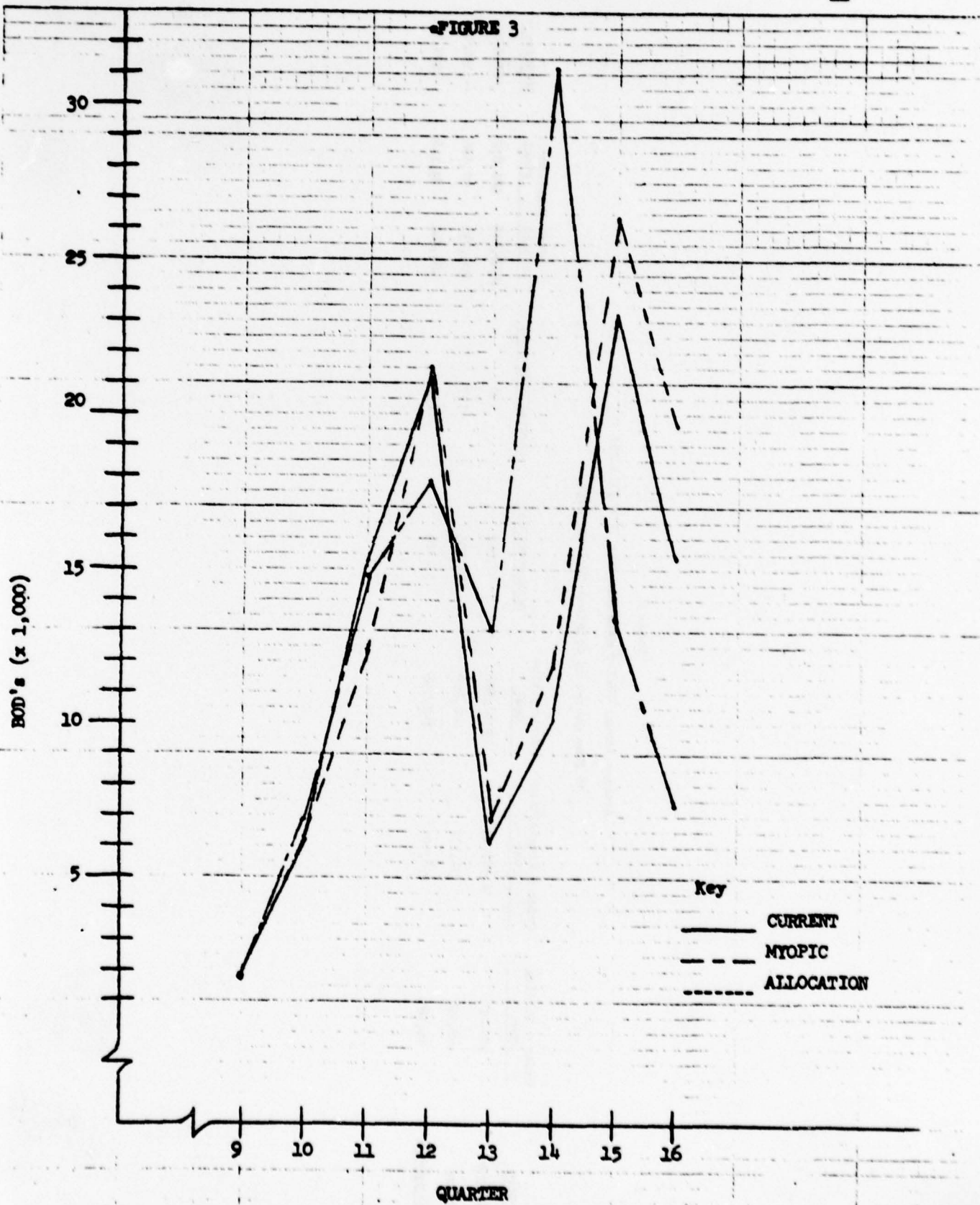


Table 2

Average Annual Performance Measures ($\lambda = \$113.25$)

38 Item Subset of Original 50 Item Sample

Policy	Order + Holding		Order + Acquisition		Acquisition		Backorder-Days	Partial Shipments	Asset Position		Difference
	Cost		Cost		Cost				Initial	Final	
CURRENT	\$46,220		\$158,791		\$142,596		47,662	190	\$184,846	\$22,812	-\$102,034
MTDFIC	48,518		157,377		142,269		53,336	155	203,733	97,686	- 106,047
ALLOCATION	46,181		158,791		142,596		53,464	220	184,846	83,116	- 101,730

Otherwise the procedures were identical.³ A list of the National Stock Numbers for the items in this second sample is provided in Table A2 of the Appendix.

The second sample of 50 was tested in the same manner as the original for all three policies using $\lambda = \$113.25$ and the $U[R, Q + R]$ initialization. The results appear in Figure 4 and Table 3. Figure 4 is a graph of the backorder-day performance of the three policies on a quarterly basis. Note that, as in Approach 1 above, the dramatic increase in backorder-day performance in [1, Figure 4] is not to be found. However, nonstationarity is still present.

Table 3 presents average annual performance measures for the three policies on the second sample of 50 items. For comparison purposes, the corresponding measures from the original sample of 50 items (Table 1) are presented in parentheses. Table 3 indicates that CURRENT policy is again slightly superior to the two alternative policies.

Conclusion Based on Experiment 2

The nonstationary behavior of some (12) items in the original sample was evidently responsible for most of the nonstationarity observed in [1]. A second sample of 50 items - chosen in a very similar manner - displayed some nonstationarity, but, compared with the original, this nonstationarity was insignificant. We can draw no valid conclusions with respect to the "representativeness" of the 12 items removed from the original sample of 50 in Approach 1 above, except, of course, to note that such items account for 12% of the 100 items sampled. However,

³ In cases where a stock number had already been chosen in the original sample, the adjacent stock number on the ranked list was chosen.

FIGURE 4

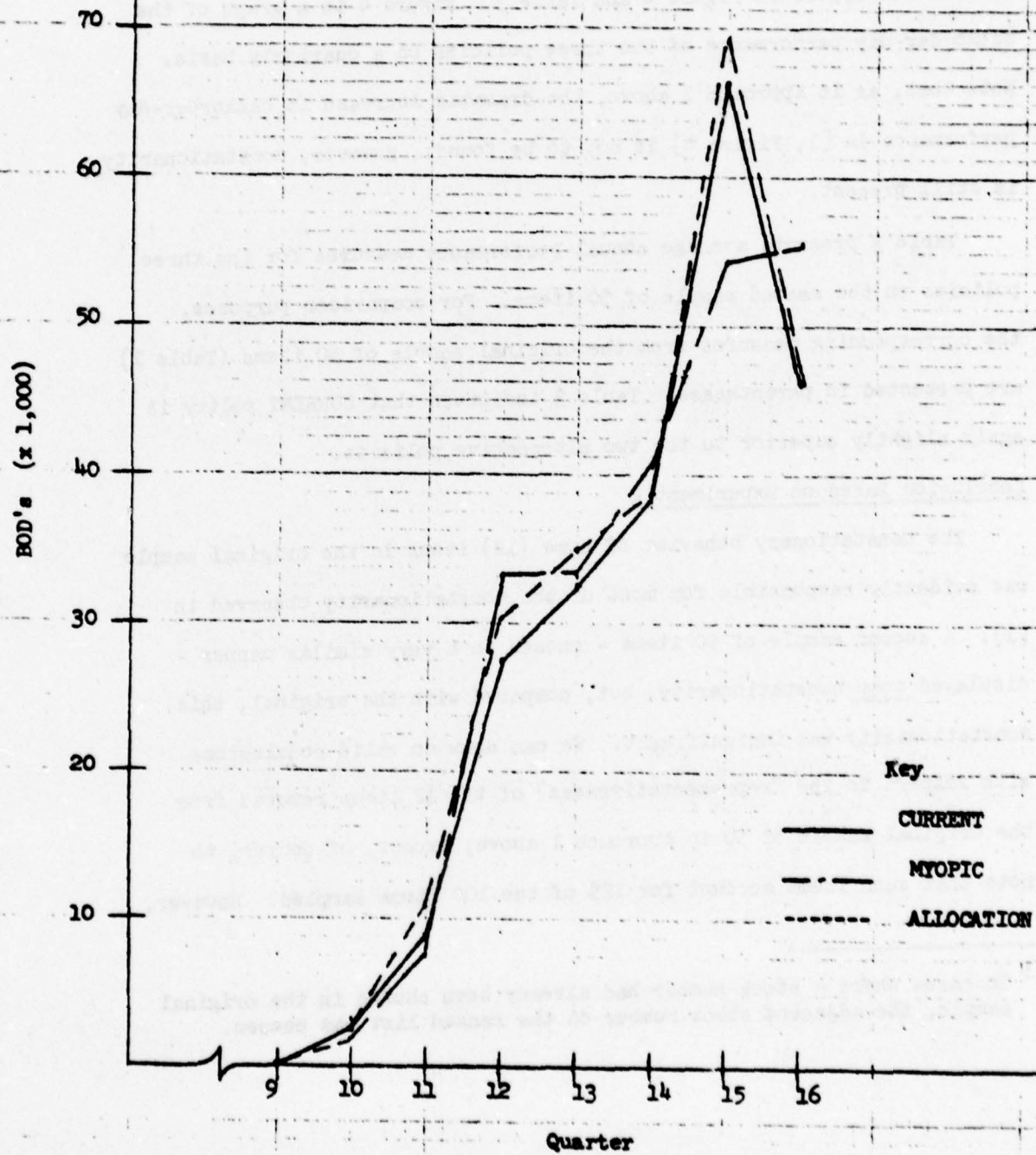


Table 3

Average Annual Performance Measures ($\lambda = \$113.25$)

Second Sample of 50 Items

Policy	Order + Holding		Order + Acquisition		Acquisition		Backorder-Days		Partial Shipments		Asset Position		Difference
	Cost		Cost		Cost						Initial	Final	
CURRENT	\$233,508		\$ 895,634		\$864,894		110,734		272		\$1,455,376	\$401,232	-\$1,054,144
	(151,364)*		(1,024,409)		(967,321)		(1,737,708)		(2,006)		(458,177)	(451,153)	(-7,024)
MTOPTC	257,226		864,126		836,304		114,839		220		1,481,250	441,241	- 1,040,009
	(164,591)		(1,005,047)		(952,330)		(1,750,134)		(1,480)		(502,788)	(504,132)	(1,344)
ALLOCATION	233,417		895,634		864,894		117,532		345		1,455,376	400,988	- 1,054,388
	(151,334)		(1,024,409)		(967,321)		(1,741,108)		(2,038)		(458,177)	(453,078)	(-4,099)

* Entries in parentheses are the corresponding measures from the original sample of 50 items.

we may conclude that the relative performance of the three policies does depend not only on the method of initialization employed, but also on the sample of items chosen for test. This conclusion is discussed further in Section VI.

IV. Experiment 3: Lead Time Reduction

Nonstationarity in the demand pattern for any item or set of items is a fact of life in managing any real world inventory system. However, nonstationarity demand poses difficulties in simulations of inventory systems when the supply lead times are long and simulated test periods are short. Such is the case in the system under study. Depot supply times for the items under study range from approximately 4 to 18 months. The demand history provided for this study was only 4 years, or 16 quarters long. One-half of this history (2 years) was used to initialize the system, the remaining 2 years (24 months) were used for test. Consequently, during the test period, the depot has at most 6 ($24/4$) or at worst ($24/18$) opportunities to resupply itself during the test period. This means that if the demand history during the test period is unlike the demand history during the initialization period -- as is likely -- the system will have little or no opportunity to adjust itself to the new circumstances before the end of the test period. Consequently, any attempt to measure the overall performance of the system will be confounded by the nonstationarity of demand.

One method for overcoming this difficulty is to artificially shorten lead times. Although this shortening is unrealistic in practical terms, it does allow the experimenter to isolate the overall long term behavior of the system simulated from the nonstationary behavior of the demand pattern. The degree of isolation depends on the amount the lead times are shortened.

In this experiment lead times were shortened by 50%. This amount is, of course, arbitrary. However, the intent of this experiment is exploratory. The items tested are the 50 items in the original sample.

The results of the experiment are given in Figure 5 and Table 4.

Figure 5 is a graph of backorder-days for all 3 policies on a quarterly basis. For comparison purposes the backorder-day performance of these same policies for the same items but full lead times, Figure 4 of [1], are also graphed in Figure 5. It is clear that shortening the lead times has had the intended effect. Backorder-days for all three policies display somewhat oscillatory, but stationary behavior between quarters 10 and 16.

Table 4 provides average annual performance measures. Examination of Table 4 indicates that the behavior of all of the three policies is similar, with CURRENT policy slightly superior to both MYOPIC and ALLOCATION.

Conclusion Based on Experiment 3

Experiment 3 clearly indicates that shortening lead times does isolate the behavior of the system simulated from the nonstationarity in the demand patterns of the items sampled. This conclusion will be further discussed in Section VI.

FIGURE 5

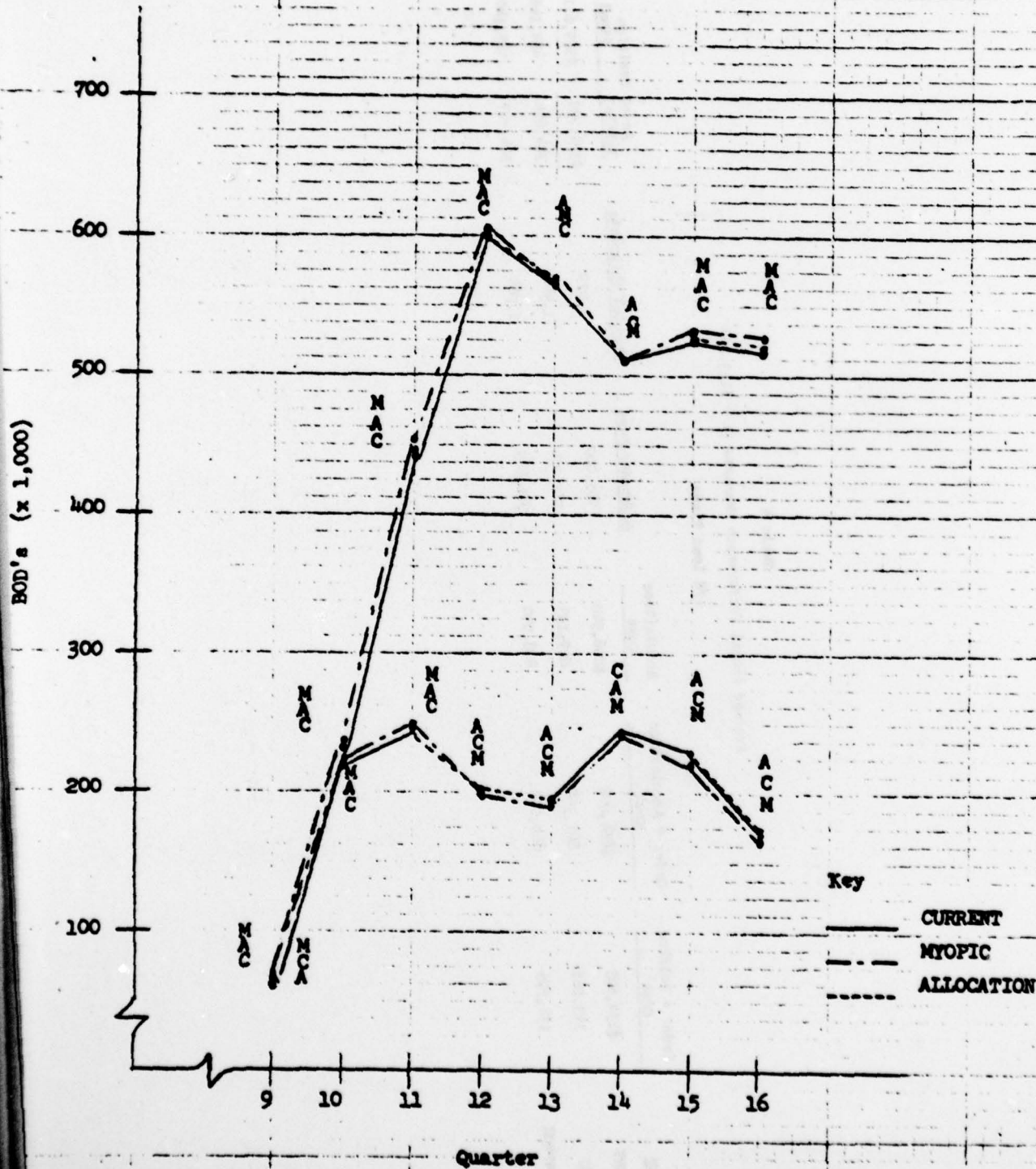


Table 4

Average Annual Performance Measures (A = \$113.25)

1/2 Lead Time

Policy	Order + Holding Cost	Order + Acquisition Cost	Acquisition Cost	Backorder-Days	Partial Shipments	Asset Position		Difference (Final-Initial)
						Initial	Final	
CURRENT	\$134,885	\$864,002	\$808,940	785,000	1,919	\$324,707	\$329,611	\$ 4,904
HTOPIC	143,266	881,368	829,193	781,004	1,440	344,654	404,146	59,492
ALLOCATION	134,795	864,002	808,940	786,849	1,964	324,707	385,140	60,433

V. Experiment 4: Test Period Extension

As described in Section IV, nonstationary demand poses difficulties in simulations of inventory systems when the supply lead times are long and simulated test periods are short. Experiment 3 dealt with this difficulty by artificially shortening the lead times relative to the test period. In this experiment, the reverse was done: lead times are held at their original, real values and the test period is artificially lengthened. The test period was artificially extended from 2 years (years 3 and 4) to 10 years by using the 4 year demand history two more times. The 10 year test period consisted of years 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, in the sequence shown. Given the exploratory nature of this study and the long computer run times necessitated by this experiment, only CURRENT policy was tested using $\lambda = \$113.25$. The items tested were the 50 items in the original sample. The results of the test are provided in Figure 6 and Table 5. Figure 6 is a graph of backorder-days for CURRENT policy over the 40 quarter extended test period. Note that backorder-day performance for the first 8 quarters of the test period (quarters 9 thru 16) is identical to that reported in [1, Figure 4]. However, thereafter backorder-days become somewhat oscillatory, but stationary nonetheless. Table 5 provides the average annual performance measures. For comparison purposes, the corresponding measures from the original two year test period are given in parentheses. It is clear from Table 5 that the behavior of CURRENT over a long test period is quite different from its behavior over a short test period.

Conclusion Based on Experiment 4

Although the construction of the longer test period was arbitrary, and perhaps not representative of real demand behavior over a long test period, the conclusion based on this experiment is clear: The long

FIGURE 6

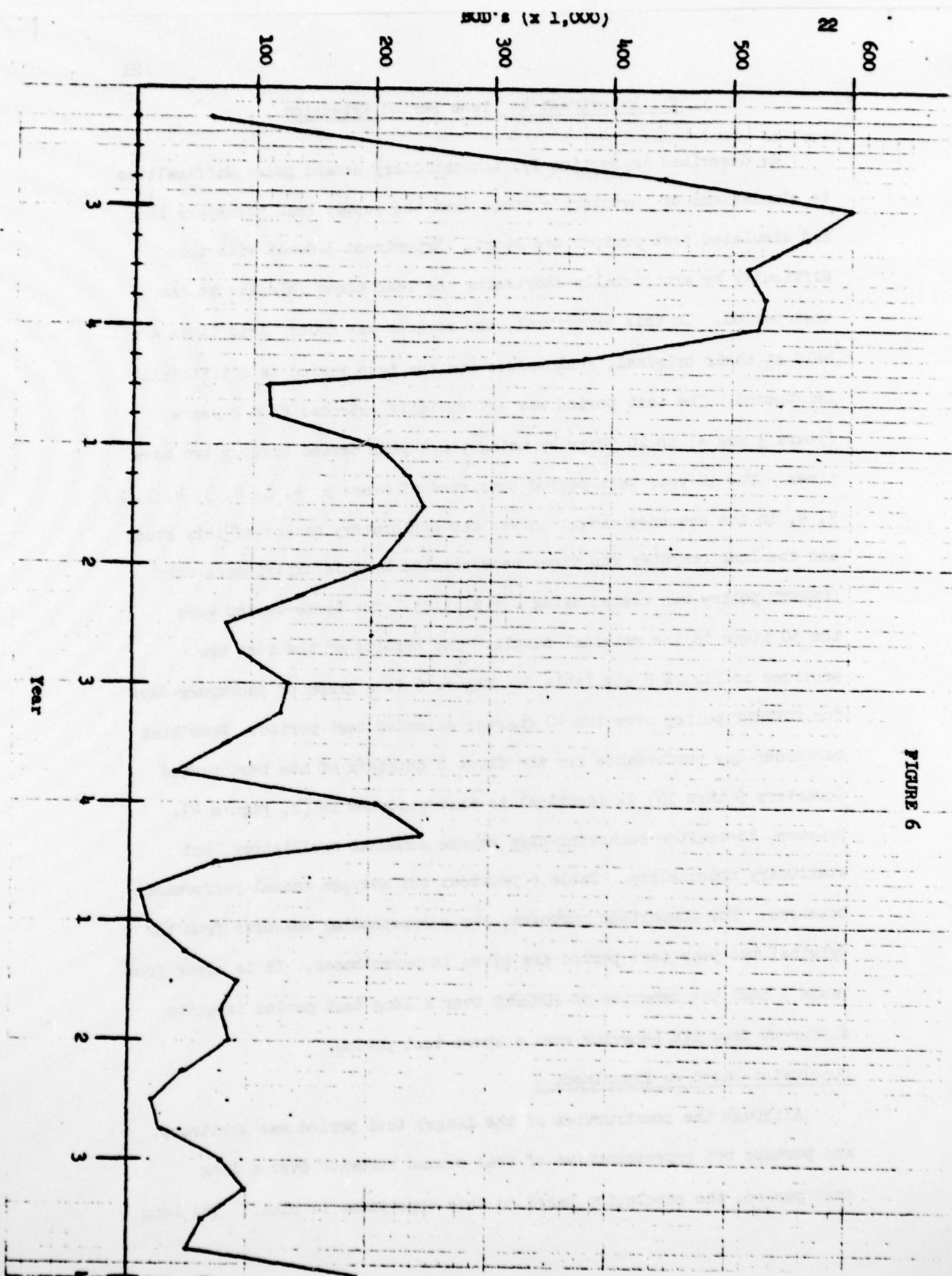


Table 5

Average Annual Performance Measures (A - \$113.25)

CURRENT Policy

40 Quarter Experiment

Order + Holding Cost	Order + Acquisition Cost	Acquisition Cost	Backorder-Days	Partial Shipments	Asset Position Initial Final	Difference
\$206,293	\$820,134	\$780,225	733,916	1,226	\$458,177 \$986,811	\$528,634
(151,364)*	(1,024,409)	(967,321)	(1,737,708)	(2,006)	(\$58,177) (\$51,153)	(-7,024)

* Entries in parentheses are the corresponding measures from the original 2 year test period.

run behavior of the policies in question is quite likely very different from their behavior over the two year test period used in [1].

VI. Discussion of Results: Suggestions for Further Study

The conclusions of the four experiments conducted in this study may be summarized as follows:

1. The long term performance of the policies examined is quite possibly different from the performance measured in the original two year test period.
2. The relative performance of the policies tested over the two year test period is heavily dependent on:
 - (a) the sample of items tested; and
 - (b) the method chosen for initialization.
3. The long term performance of the policies in question may be (approximately) simulated by:
 - (a) artificially shortening lead times; and/or
 - (b) artificially extending the test period.

The implications of these findings for future work are clear:

1. If the relative long run performance of the CURRENT, MYOPIC, and ALLOCATION policies are to be appropriately tested, it is essential that data for a long period of time (e.g., 8 - 10 years) be collected or constructed.
2. It is also essential that the policies be tested on a large sample of items with varying demand behavior. The tests conducted here are not sufficient to indicate the appropriate sample size, but it is clear that samples of 50 are not large enough.
3. Further simulation work must address itself to the sensitivity of system behavior and policy performance to initialization procedures. Of course, it is well-known that sensitivity to initialization procedures decreases as the length of the test period increases. Nonetheless, attention must be paid to this issue.

Bibliography

1. Schwarz, L. B., "An Examination of the United States Air Force (Q,R) Policies for Managing Depot/Base Inventories," October, 1976. Prepared under Contract F33615-76C-5369.

APPENDIX

Table A1

National Stock Numbers of Items in Original Sample

<u>Depot</u>	<u>National Stock Number</u>
Ogden Depot:	1430008429324
	1560000043727
	1560000641083
	1560000750929 *
	1560001092466 *
	1560001922246
	1560001924623
	1560004416323
	1560004777728
	1560006909834
	1560007232675
	1560007886401 *
	1560007886507
	1560007946304 *
	1560008592935
	1560008592959 *
	1560008601010
	1560008715949
	1560009109121
	1560009169904
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	1560009313633
	1560009317395
	1560009533664
	1560009979210
	1620009423451
	1650000225451 *
	1650000885767
	1650004197922
	1680001337096
	1680007831649 *
	2915007385540
	3040009565415
	5306009371975 *
	5310004790272
	5315008113772
	5365004197823
	5895006911354
	5935004833294
	5940008782091
	5961000584170
	6615009087449
	6680008945069
Oklahoma Depot:	1650000500440
	2840000203350 *
	2840007986003 *
	2840007989185
	2840009453246 *
	2925001277816
	2995007988157 *

* = removed for 38-item subset

Table A2

National Stock Numbers of Items in Second Sample

<u>Depot</u>	<u>National Stock Number</u>
Ogden Depot:	1430001309147
	1430004761198
	1430007946150
	1430008114729
	1430008249121
	1430009972076
	1560000658943
	1560001054888
	1560001351619
	1560004375445
	1560004721269
	1560005660602
	1560006069652
	1560007881990
	1560007882073
	1560008194478
	1560008579316
	1560008598627
	1560008601045
	1560008729540
	1560008995993
	1560009018209
	1560009084883
	1560009192756
	1560009242982
	1560009277775
	1560009366609
	1560009414214
	1560009438766
	1560009672531
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